MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROGRESS REPORT

RESEARCH ON INTEGRATION OF VISUAL AND MOTION CUES FOR FLIGHT SIMULATION AND RIDE QUALITY INVESTIGATION

NASA GRANT NGR 22-009-701

APRIL 1974 - OCTOBER 1974

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INTRODUCTION

The primary goal of this research program is the development of multi-input models for the optimum use of visual and motion cues in flight simulation. Past reports have empasized development of models for the processing of visual cues associated with structured and non-structured visual scenes, refinement of models for spatial orientation based upon semicircular canal and otolith function, the combination of linear and angular acceleration cues in non-visual motion sensing, and the integration of visual and vestibular cues associated with moving visual fields. The work which has taken place during the last six months has been concentrated on

(1) the testing of the applicability of our models by applying the Ormsby model for visual-vestibular interactions to a realistic simulation

(2) design and development of a five degree of freedom orientation indicator

(3) refinement of the LINK GAT-1 display system

(4) extending the study of linearvection in the vertical direction

(5) continued investigation of the relationship between vestibular stimulation and visually induced roll, using the indicator of counter-rolling eye movements

(6) experiments on simulator visual thresholds

VISUAL-VESTIBULAR INTERACTION MODEL

During the summer of 1974, one of the graduate students of the Laboratory, Joshua Borah, worked at the Langley Research Center. The major goals of his work were to develop a program to predict moving base simulation fidelities based on the Ormsby (1974) perception model, to use this program to predict the optimum simulation of a particular motion when subject to specific constraints, and to test these by performing experiments on the Langley Realtime Dynamic Simulator.

A fidelity prediction program was written and is presently being modified in light of the trials during the summer. The difference in acceleration perception caused by the "test motion" and that caused by the attempted simulation is computed (perceptions being calcualted by the vestibular model). This difference is obtained as a percent of the test motion perception. These quantities are added at each sampling point, and their sum averaged over the whole run. In its present form, the "cost" program weights acceleration and attitude errors equally. When dividing by test motion perception to compute percents, the divisor is not allowed to go below a minimum value in order to avoid infinite cost functions. The most reasonable way to choose these minimum divisors is to relate them to perceptual thresholds, since, if an error is smaller than the threshold value, it is unlikely to be important. The threshold value for longitudinal acceleration (the predominant motion in this experiment) is roughly 0.005 g. When a 0.005 g step is applied to the Ormsby model, the maximum indication of acceleration perception is about 0.0038 g. Therefore, 0.0038 g is used as a minimum acceleration divisor. Since the model indicates attitude perceptions which eventually line up with specific force directions fairly precisely, 0.005 radian is used as the minimum attitude divisor. Although it appears to give reliable predictions so far, it has been tried very little. Further testing on varied situations should be done to ensure that it gives consistent and reasonable results.

The experiment designed to test the program involved giving the subject simple isolated motions that could be produced exactly on the Langley Realtime Dynamic Simulator, followed by motions designed, with the help of the vestibular model, to produce as nearly as possible the same sensations, while requiring less simulator motion.

The subject was asked to indicate his perceived acceleration with a panel of buttons (choices included forward, backward, up, down, tilted back, tilted forward, and not sure). He was instructed to press one or more buttons as long as the sensation remained. At the end of each run, he was asked to describe verbally the sensations felt and additionally, to rate the second run of each set with respect to the first (choices here are - identical; qualitatively identical but sensations weaker (or stronger); very similar, but not identical; some similarities; very different; and none of the above).

When the experiment was attempted, several hardware problems were encountered. The most severe difficulty lies in the inability of the RDS to reproduce a smooth acceleration command, apparently caused by pendulous oscillation and some type of time delay or lag. Several solutions present themselves, but all will need to be tested on the actual equipment before the problem can be solved.

Other modifications of the experiment devised during the summer will include a modification of the rating scale which proved confusing and ambiguous. Subjects tried to indicate perceived acceleration, but much of the resulting data correlates more closely with velocity. This may, however, be a function of the uneven quality of the ride due to the mechanical problems mentioned above. We may use a 5-axis control stick designed in the Man Vehicle Lab during the summer to extend the amount of information to be gained from each experiment. With the control stick, subjects would be able to indicate magnitude, as well as direction, which should be especially useful in monitoring orientation perception. The use of this stick will also provide a more continuous report of orientation than did the button system and may pick up small changes in perceived orientation.

FIVE DEGREE OF FREEDOM ORIENTATION INDICATOR

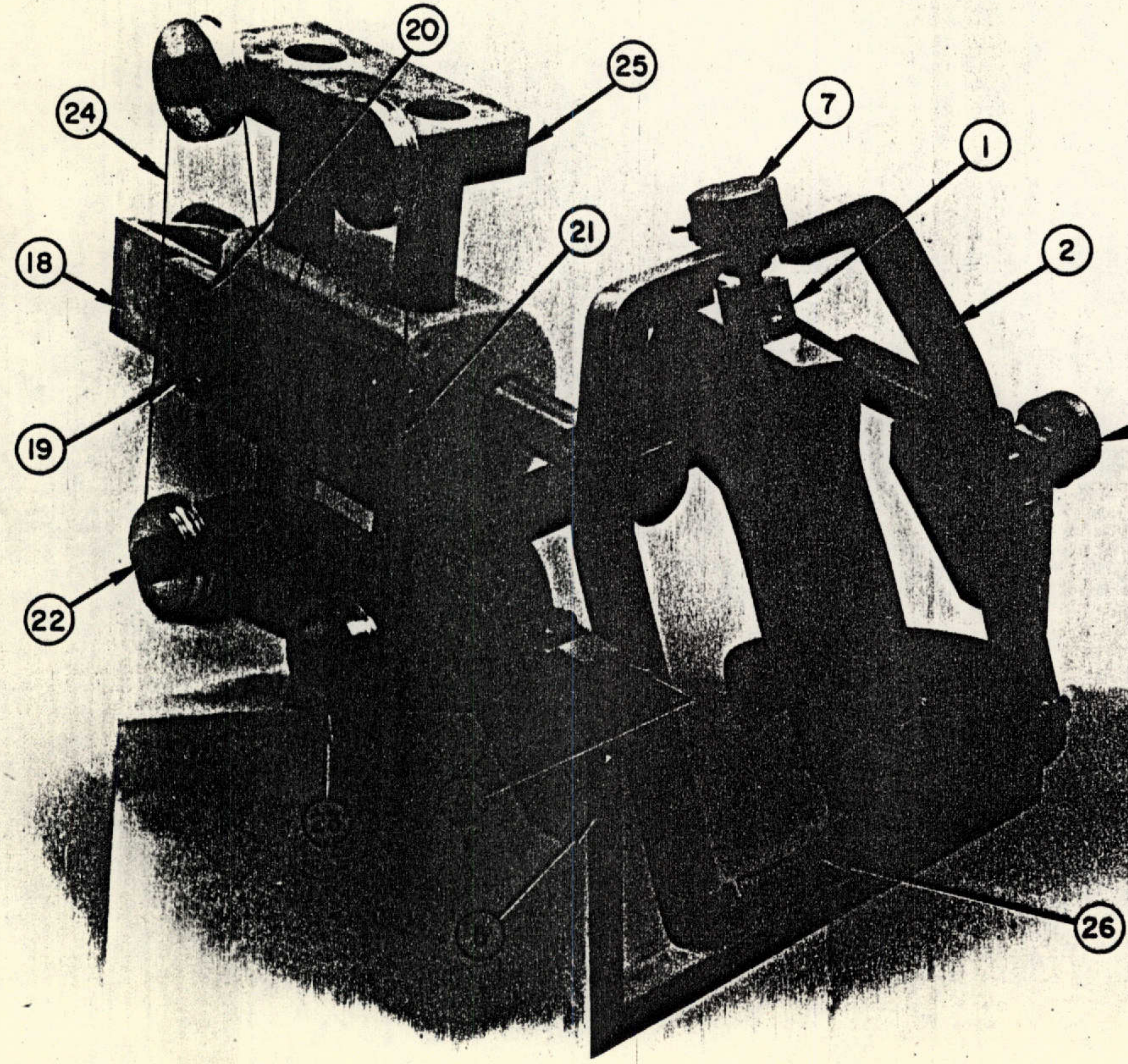
Work was completed on an orientation indicator, which has five degrees of freedom. This indicator is capable of providing, by means of voltage readouts, a history of a subject's perception of his orientation, while the subject is undergoing various linear and angular rotations. The device uses a conventional gimbal system with each gimbal linked to a linear potentiometer so that the output (voltage) will be proportional to the input (gimbal angle). To measure linear accelerations, along the x and z axes, the same general princi^le was used. In this case, however, the input would be a linear motion, i.e., pushing the hand forward, backw rd, up or down, and thus it would be necessary to u e a linear motion or slide potentiometer instead of the conventional rotory type.

In the final design, it was decided not to approximate the linear motions with circular arcs of large radius, but rather to attach the outermost gimbal to a rod which would still be free to rotate (roll motion), but which would also be free to slide inside a stationary casing. A slide potentiometer would be attached between the rod and casing thus giving a readout of all x-axis motion. Y-axis motion could have been realized similarly, however, since natural motions seldom occur in that direction (except in the sense of rotations) and because of the inherent sub-system redundancy, it was decided that y-axis linear motion was not necessary.

The first attempt to implement z-axis motions using a similar system was unsuccessful due to the large torques involved. To counteract this torque, a second z-axis bar was added along with a set of four pulleys which were wound tightly with piano wire. The wire was wound tightly enough to prevent slipping so that the turning of one pair of pulleys would cause the other to turn at the same ratem thus allowing the hand to move up and down freely.

The completed instrument is shown in Figure 1. The development was done by A. Salih as part of his Engineer's Thesis, with only equipment support from this grant.

FIGURE 1



SYSTEM - TOP LEFT ANGLE VIEW

LINK GAT-1 DISPLAY SYSTEM

An improved wide angle moving field display system was designed for our continued work on linearvection and circularvection in flight simulation.

The present design has taken the best features of the system designed and built by R.E. Murphy during 197-1972 and a moving bar generator designed by J. Swan of the psychology department at M. I. T. and has added certain improvements. The object was to create a more versatile and reliable display system.

The display system is comprised of two independent parts: the display generator and the optics unit. The generator is a Leitz Prado Universal Profector with servo driven 35mm film loop. The servo drive has a built in tachometer which gives an accurate indication of film speed. The film loop is easily removed and replaced and two bar width/bar separation formats are so far available for use. Allowance has been made for the future inclusion of a second loop at a right angle to the first, for use in generating more complex displays. The film drive and feedback can be interfaced with the present hybrid computer system.

The optics unit is an image rotator with 66 mm working aperture followed by beam splitters and mirrors which adjust image orientation and deliver it to the side and front windows of the LINK GAT-1. The image rotator is servo-driven (also from the computer if desired), and a potentiometer is mechanically coupled in to render positional information. Construction was nearly complete at the end of October 1974.

LINEARVECTION

Experiments were conducted over the spring and summer to study the effects of visual stimulus on induced sensation of motion in the vertical direction. The experimental setup was similar to that employed in previous experiments involving the projection of uniformly spaced stripes onto the translucent windows of the LINK trainer. The stripes were driven at 2 speeds (10 and 20 cm/sec). Sequences of up and down stripe motion were given to subjects seated in the darkened cabin of the motionless trainer. The subjects were instructed to indicate subjective velocity by moving a spring loaded stick. Calibration of the stick was achieved by using two long duration exposures of 20 cm/sec motion in each direction until a steady state maximum velocity was achieved. The subjects were then told to use the full deflection for that velocity and to estimate partial stick deflection for percentage of velocity experienced in the experiment. The records of subjective responses were stored on tape for further analysis.

Data from five subjects was used for the analysis. Causal relationships both in magnitude and phase were sought between the presented visual stimulus and the subjective responses. A program developed earlier was used to compute the correlation coefficient

$$\rho_{XY}(\tau) = \frac{\overline{X(K)Y(K+\tau)} - (\overline{X(K)}\ \overline{Y(K)}}{([\overline{X^2(K)} - \overline{X(K)^2}]\ [\overline{Y^2(K)} - \overline{Y(K)^2}])^{1/2}}$$

$$\tau = 0,1,2,\ldots,9 \text{ seconds}$$

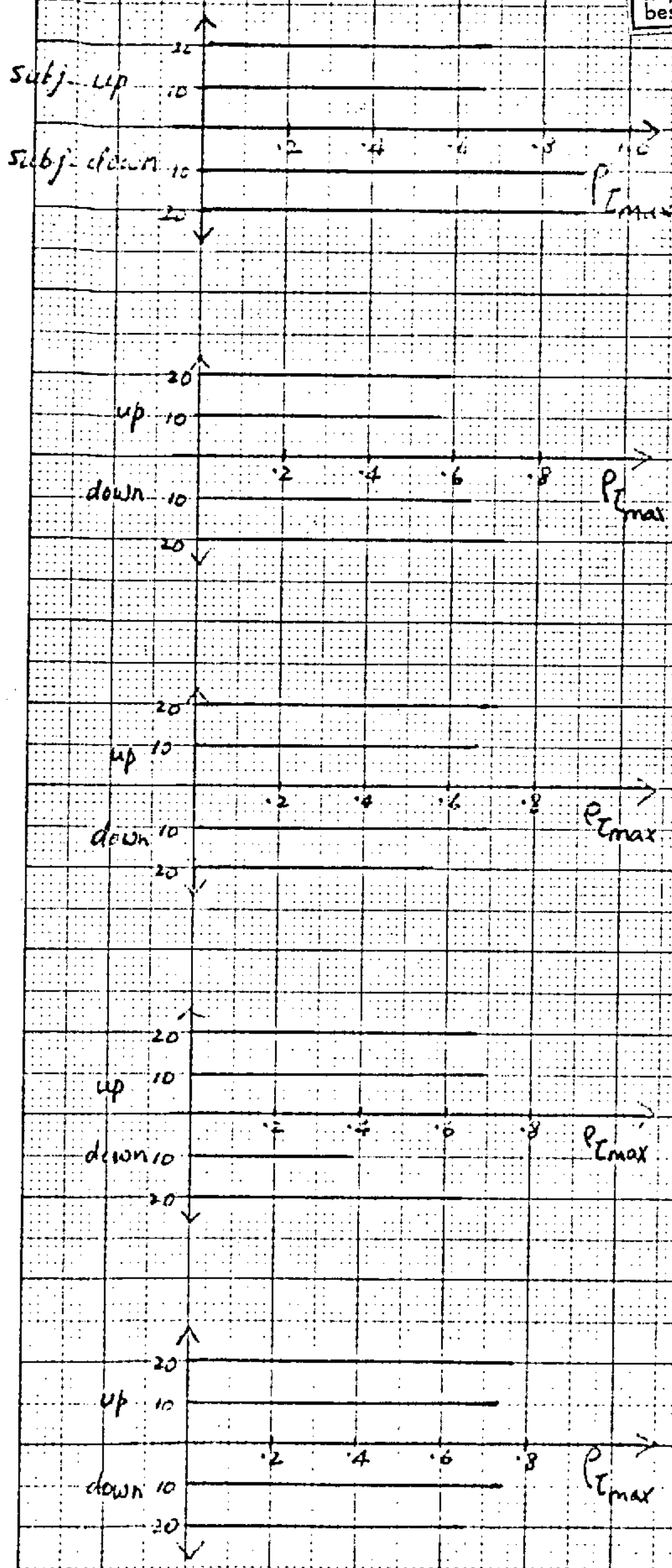
where X(K) and Y(K) are the stripe velocity and subjective response respectively and τ is the correlation time used. For each subject, a separate correlation was run for four different exposures of velocity levels. Correlation curves $\rho(\tau)$ for all subjects were smooth with well defined maxima. If we define τ_m,

$$\tau_m = \arg\max \rho_{XY}(\tau)$$

then τ_m represents the best fitting time delay in subjective response.

Figure 2 shows for each subject the maximum coefficient $\rho(\tau_m)$ for the four stripe velocities. No significant differences could be seen for the different speeds and directions.

Figure 3 shows, for each subject, the best fitting time lag τ_m, also for the four stimulus velocities. Here it could be observed that for all cases but one, in which the response delay actually decreased for an increase in stripe velocity in the same direction, all other response latencies either remained the same or increased for an increase in strip velocity. This is clearly seen in Figure 4, where the distributions of τ_m across subjects is plotted for the four velocity levels. In the upward direction (stripes down), the average response



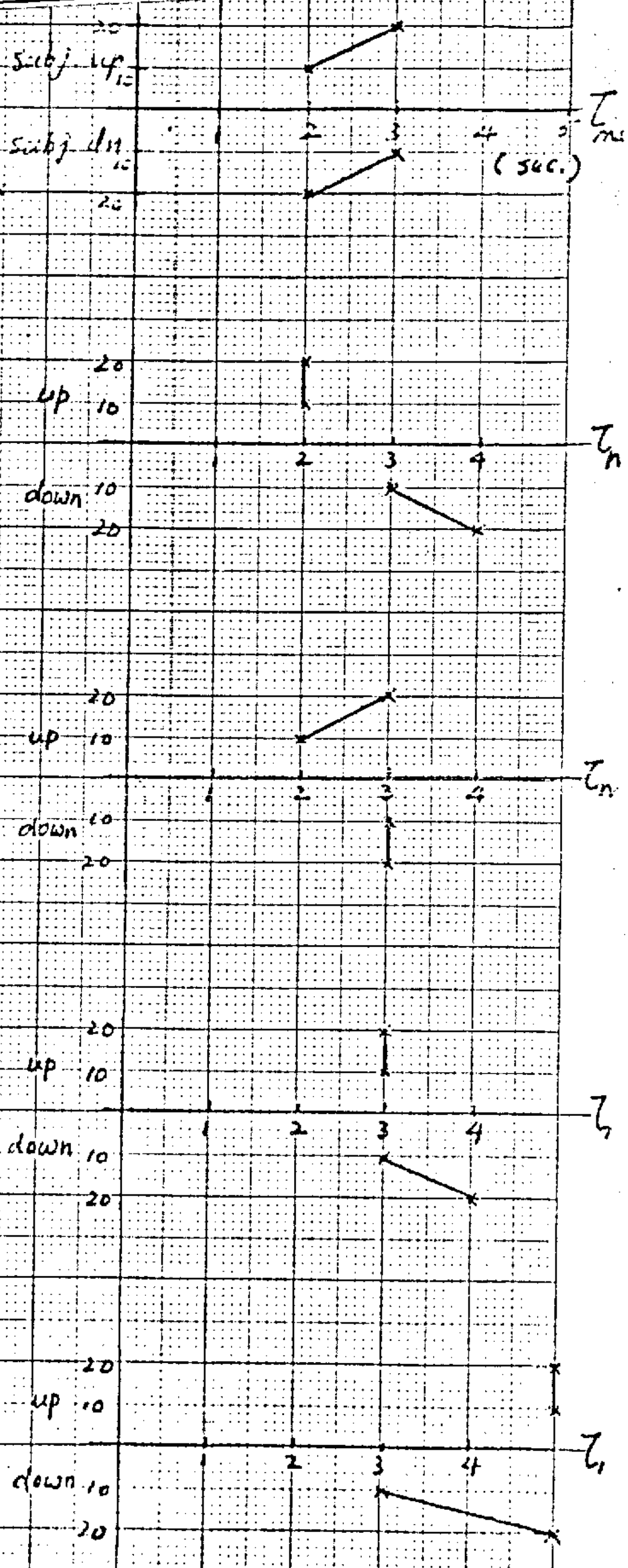


FIGURE 2

FIGURE 3

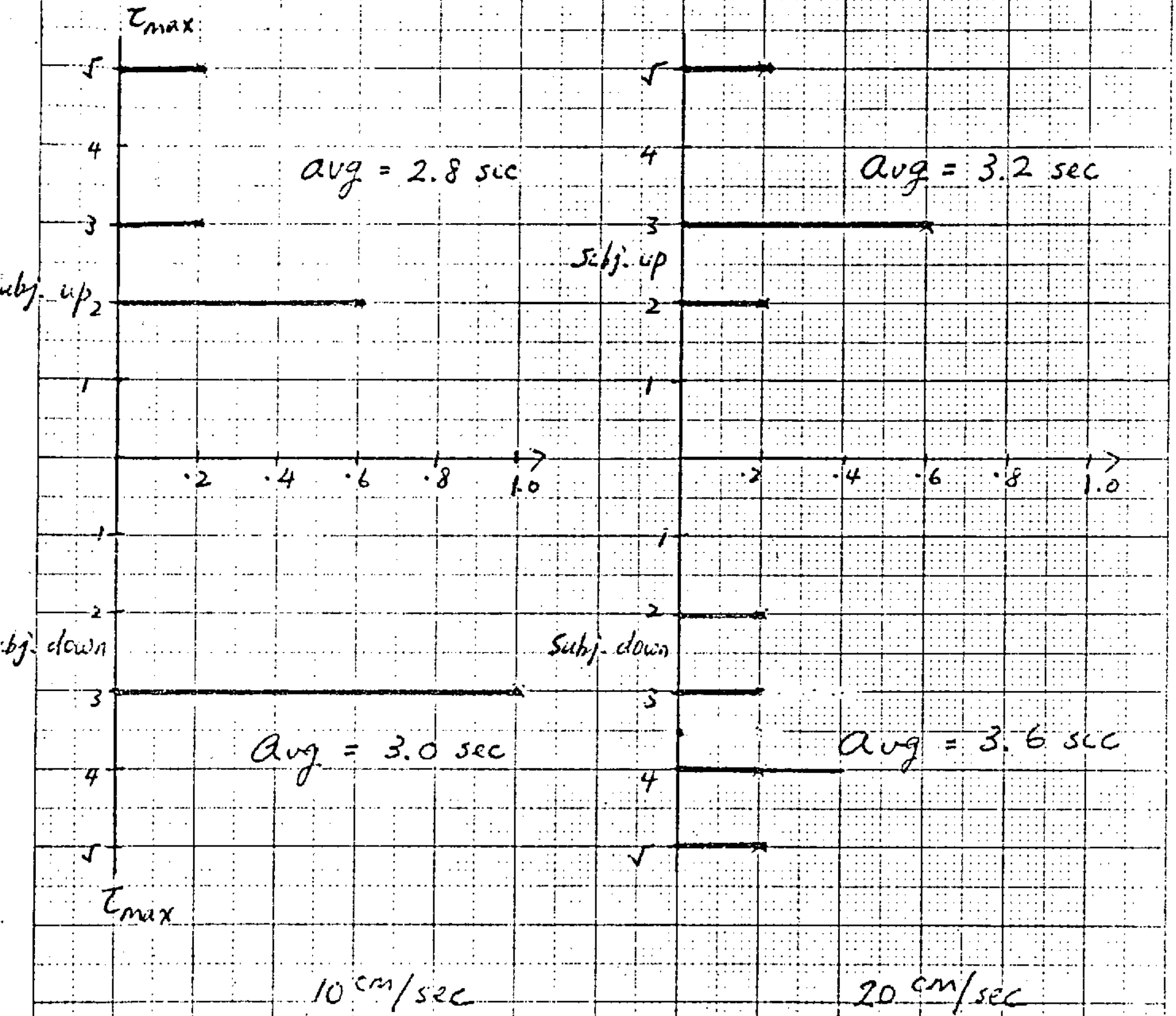

τ_{max}
avg = 2.8 sec
avg = 3.2 sec
subj. up
subj. down
avg = 3.0 sec
avg = 3.6 sec
τ_{max}
10 cm/sec
20 cm/sec

FIGURE 4

latency was larger by 0.4 seconds with the higher stripe velocity. For the subjective down direction, the increase was 0.6 seconds. A less significant difference appears in a comparison of response time for the two directions of induced motion. Evocation of a downward sensation of motion was somewhat slower. There was a difference of 0.2 seconds for the slower speed and 0.4 seconds for the faster.

Figure 5 shows some representative waveforms of response to steps of stripe movement. The top traces show a fast acquisition of some nonzero velocity, after an initial delay. This is followed by a period of acceleration that levels off almost to zero. This type of subjective response was by far the most commonly observed. The bottom traces show another type of response, which was less frequently encountered. Here the subject showed an acceleration from rest rather than from some initially acquired velocity. The acceleration did not seem to level off appreciably during the exposure of stripe motion.

All subjects reported encountering a drift sensation in the opposite direction after the stripes were stopped. Thus for instance, a slow sinking sensation was often felt after the subject was exposed to downward moving stripes (which would induce a sensation of upward motion). This sinking and rising feeling persisted for no more than one or two seconds after the stripe motion had ceased.

A. Chao and W. Chu worked with Professor Young on this project.

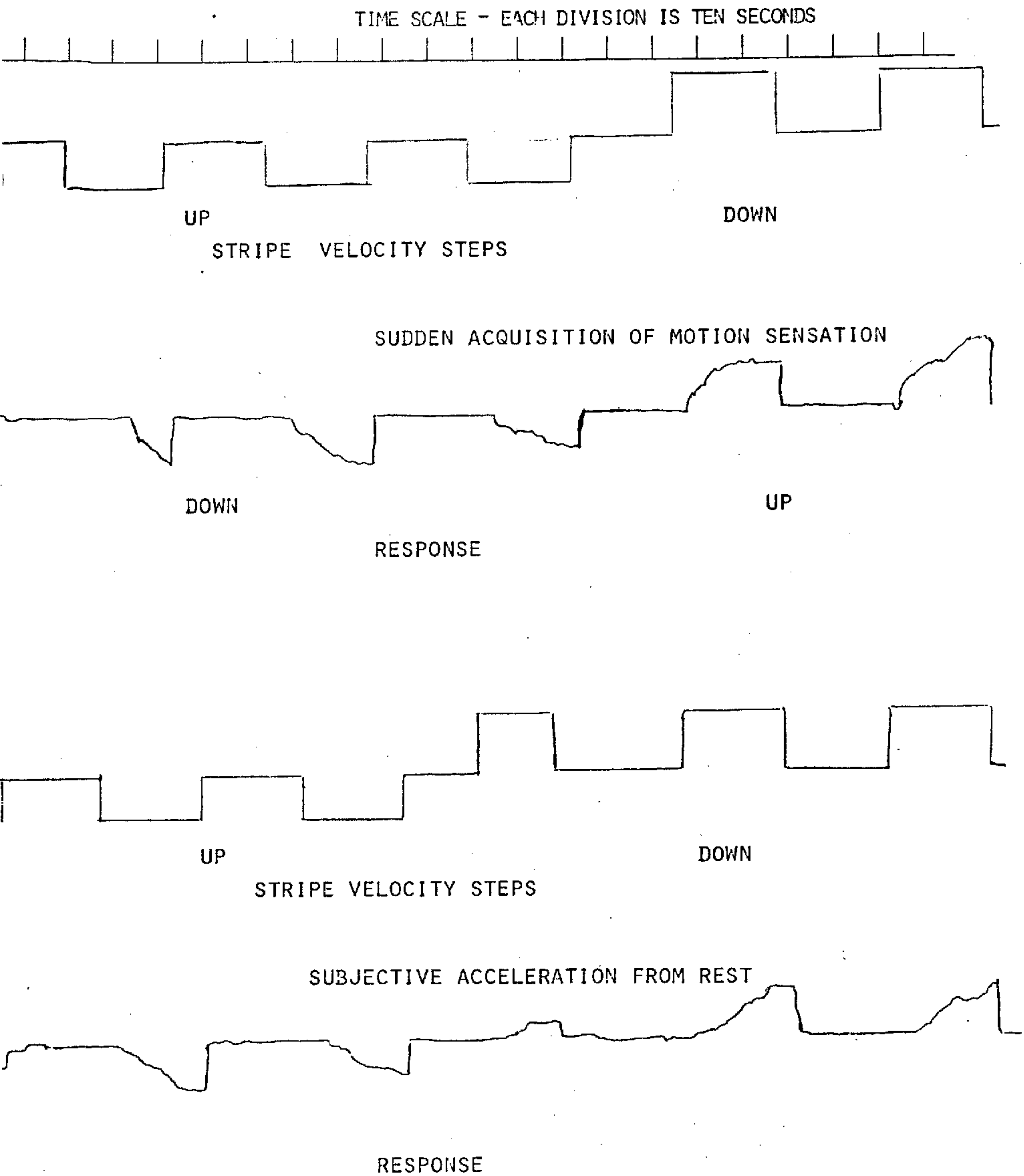

TIME SCALE - EACH DIVISION IS TEN SECONDS
UP
DOWN
STRIPE VELOCITY STEPS
SUDDEN ACQUISITION OF MOTION SENSATION
DOWN
UP
RESPONSE
UP
DOWN
STRIPE VELOCITY STEPS
SUBJECTIVE ACCELERATION FROM REST
RESPONSE

FIGURE 5

VISUALLY INDUCED ROLL

Visually induced roll (VIR), an illusory motion induced by a large rotating visual field, is characterized by the limit of the induced tilt angles. Although individual subjects showed significant differences in their indicated induced tilt angles, nevertheless, no subject tested so far has shown a continuous visually induced sensation of motion as in cases of circular vection. This limit of visually induced tilt angles is presumably because information from the labyrinthine organs (particularly the otoliths) constrains the visual information. The fact that VIR has been found to be a function of head orientation seems to strongly support this explanation.

VIR is usually directionally asymmetric. VIR induced by left rotating visual fields are not equal to the ones induced by right rotating visual fields. This effect is consistent for each subject and significant in most individuals tested. Similar asymmetry in 'otolithic strength' as revealed by measurements of ocular conterrolling and subjective tilt has been reported by the correlation between the two remains unknown.

In this investigation, the aim was to provide some functional evidence for modelling the interaction of visually induced and labyrinthine sensed lateral tilts. To this end the following experiments were performed in our NE-2 flight simulator.

1. Tests on the correlation betwen VIR bias and counterrolling bias in real tilts.

2. Tests on the correlation between VIR bias and visually induced counterrolling bias.
3. Measurement of subjective tilts (either VIR or real tilt) and counterrolling under various conditions.
4. Comparison of the after-image and photographic methods in obtaining counterrolling.

From results obtained in this study and other reported results, a model is being developed to describe the non-linear behavior of the interaction between visually induced and labyrinthine-sensed lateral tilts.

The experimental results which should be described by the model are the following:

1. The visually induced and labyrinthine-sensed lateral tilts share a common asymmetry which is not necessarily at the peripheral level. This is supported by the very significant correlation between VIR counterrolling bias at upright position and counterrolling bias from real tilts.
2. The fact that counterrolling in each direction did not, itself, correlate with VIR, but that

counterrolling <u>bias</u> correlated very significantly with VIR <u>bias</u>, suggests that counterrolling and VIR cannot be considered as parallel sensory outputs, rather they should be additive with some third element. The third element seems to be attributable to visual information which bypasses the asymmetry. In other words, the asymmetrical information from the counterrolling eye movements is bypassed by a visual signal with a gain which varies with individual subjects. Since the gain varies with the individual subjects, the rollvection would not correlate with the counterrolling. However, in the calculation of of the biases, correlation is possible since the

This work was carried out by J. Tang of our Laboratory, in collaboration with Professor Richard Held of the Psychology Department of M.I.T. Dr. Held is working under NASA Grant NGL 22-009-308.

SIMULATOR VISUAL THRESHOLDS

The problem of measuring human capabilities with threshold or near-threshold stimuli has always been a major interest of psychologists. The results are known to be sensitive to the experimental protocol and the data processing techniques used to evaluate the results. In developing psychometric functions when the stimulus is present on some trials and not on others, it was a common procedure to correct the psychometric functions for "guessing" by the subject. More recently, other threshold theories have been developed which recognize the two major components of the perceptual of near threshold stimuli: the sensory component or sensory capability, and the decision component or response bias.

The Theory of Signal Detectability (TSD) is one method of approaching these problems and has been used under many conditions to separate the sensory component from the response bias present in all individuals. The major problem with using TSD as it might be applied to the determination of visual thresholds in the simulator arises from the fact that the theory has been developed for random variables, i.e., independent presentations of "signal plus noise" or "noise alone" and has not been used for random processes. In work in this grant, and a companion grant, we have been extending TSD to random processes. In particular, we have found that it is still possible to separate the sensory and decision related processes in spite of the very strong perseveration of response (response bias) associated with a dynamic stimulus presentation. In other words, even through the subject is very likely to respons "signal plus noise" just because he had been saying that previously, we are still able to determine the actual sensory capabilities of the subject. E. Gai has been working in this area.

SIMULATOR EXPERIMENTS

We have undertaken the preliminary planning for visual descrimination experiments to be perfromed in the Langley Simulator, preferable using the visual attachments currently available. These experiments would determine the visual thresholds of important peripheral variables such as long/short, right/left as a pilot proceeds down the glide slope.

Aim point

Glide slope (high or low)

Localizer (right or left)

Flight path angle

Vertical velocity or glide slope velocity

Lateral velocity

The major items to be resolved before the beginning of the tests are the generation of trajectories (these can be recorded on video tape and played back for all subjects), response mechanism (the method for the subject to indicate high/low, or right/left, or a rating scale appropriate to these responses), and the storage of data for easy retrieval. We have developed programs which will provide a rapid and efficient method for computing the sensory parameters (detectability or d' for TSD) when these data become available.

One the preliminary experiments have been performed to refine the experimental method and data collection/processing procedures, it would be of interest to compare the thresholds of various attachments at Langley and/or evaluate the effects of various visual aids to such as VASI lights or use of collimating lenses on perceptual response.

FLIGHT TESTS

The ultimate application of these techniques would be the comparison of the perceptions obtained in the simulator and those obtained in flight. We feel that it would be a relatively straightforward method for obtaining in-flight perceptual responses if it were possible to simultaneously record ILS deviations and DME readings, and the response of the subject. This could be done relatively inexpensively using the basic IFR instrumentation on a light aircraft. The in-flight and simulator responses would be compared to determine the differences between the perceptions.

PUBLICATIONS (1974)

Berthoz, A., Pavard, B. and Young, L. Rôle de la vision péripérique et interactions visuo-vistibulaires dans la perception exocentrique du mouvement lineáre chez l'homme. Comptes rendus (Paris) 278:1605-1608. 1974.

Henn, V. Young, L., and Finley, C. Vestibular nucleus units in alert monkeys are also influenced by moving visual fields. Brain Research 71:144-149, 1974.

Henn, V., Young, L. and Finley, C. Unit recording from the vestibular nucleus in the alert monkey. Abstract. Paper presented at the European Brain and Behavior Society Meeting, 1974.

Ormsby, C.C., and Young, L.R. Nonlinear model for the perception of static orientation. Fortschritte fur Zoologie, (in press), 1974.

Tang, J.T., Held, R., and Young, L.R. Interaction of visually-induced and labyrinthine-sensed postural tilt. Proceedings of the Fifteenth Annual Meeting of the Psychonomic Society, 1974.

Yasui, S., and Young, L.R. Eye movements during after-image tracking under sinusoidal and random vestibular stimulation, Proceedings of the Wennergren Symposium on Ocular Motility, Stockholm, 1974.

Yasui, S., and Young, L.R. Perceived visual motion as effective stimulus to pursuit eye movement system. Science (in press) 1974.

Young, L.R. Role of the vestibular system in posture and movement. In: Medical Physiology (Mountcastle, editor) C.V. Mosby Co. 1974.

Young, L.R. and Oman, C.M. Influence of head position and field on visually induced motion, Proceedings of the Tenth Annual Conference on Manual Control, Wright Patterson AFB. 1974.

Young, L.R., and Henn, V. Nystagmus produced by rotation of monkeys. (in preparation).

Young, L.R., and Henn, V. Selective habituation of vestibular nystagmus by visual stimulation. Acta Otol. 77:159-166. 1974.

Young, L.R., Oman, C.M. and Dichgans, J. Influence of head orientation on visually induced pitch and roll sensations. Aerospace Med. (in press) 1974.